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Report to the Naval Research Laboratories
on the Determination of

MECHANICAL PROPERTIES OF
SONAR DOME RUBBER WINDOW MATERIAL

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September 1985

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Mechanical properties of the steel cord/rubber composite material used to make sonar dome rubber windows were determined. The in-plane properties of a single steel cord/rubber lamina were determined. Also determined were the bending stiffnesses of 5-poly laminates, and the in-plane shear stiffness of a 5-ply laminate in torsion.

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1. INTRODUCTION

The purpose of the present studies under agreement with NRL is the determination of mechanical properties of Sonar Dome Rubber Window laminas and laminates. In order to make reasonably accurate engineering estimates through the use of powerful computer codes it is necessary to provide meaningful material characterization. The intent here is to first determine the in-plane orthotropic properties of the laminate as well as the bending stiffnesses. These properties can then be tested on small panels on which experimental deflection tests can be conveniently performed. Having confirmed the appropriateness of the material characterization it would then be feasible to proceed to the more complex analysis of a full SDRW, special attention being given to the seam area where failures have been observed.

Three sets of measurements were performed: First, the in-plane properties of a single wire/rubber lamina were determined. Following that the bending stiffnesses of a laminate were measured, followed by the in-plane shear stiffness of a composite laminate.

2. IN PLANE PROPERTIES OF A SINGLE LAMINA

There are three in-plane stiffnesses to be determined in these tests: The modulus in the wire direction, the modulus transverse to that and the shear modulus, allowing wires to move parallel to each other. From these properties those of a compound lay-up could be computed.

Although the properties in the direction of the wires and normal to them should be computable from the steel and rubber properties by the rule of mixtures, it is preferable to make those measurements directly. In fact, that is a much safer approach because the wires are not monolithic so that their stiffness is difficult to asses in concert with the deforming rubber.

Accordingly, strips of lamina material were cut from supplied large sheets. The Young's modulus in the direction of the wires was measured by extending a strip of the single layer material. The ends of the wires were bared so that the grips of the test machine held directly on to the steel wires. This procedure yielded a value of

$$E_1 = 1.2x10^6 \text{ psi.}$$

A similar process except for the baring of the wires yielded a modulus transverse to the wires of

$$E_2 = 940 \text{ psi.}$$

This value compares reasonably with that for the homogeneous rubber which has a modulus of about 600 psi.

For the shear behavior a strip of the single lamina was clamped along lines parallel to the wires and 1.98 inches apart. Upon moving these clamps parallel to each other and recording the necessary force to produce a given displacement, resulted in a shear modulus of

$$E_{12} = 264 \text{ psi.}$$

In addition the modulus of a strip having the wires run at 45 degrees with respect ot the tension axis was measured, which yielded a value of $E_{45} = 5.1x10^3$ psi. No further evaluation of this quantity was carried out, the idea being that it would provide a check on our ability to compute the inplane properties, including the 45-degree-modulus, from the other three quantities. These are all the in-pane properties determined to date on single-layered laminae.

3. INTERACTION WITH CODE CALCULATIONS

Following the verbal transmission of these data to R. Man the simple problem of a plate under lateral pressure was analyzed at his facility. For this problem experimental data on a typical SDRW material was available from Navy in-house-tests, so that a direct comparison between experiment and code computations could be made.

Subsequent discussions with R. Man indicated computed lateral deflections that were considerably larger than those measured. It turned out that for these calculations linearly elastic deformation theory had been assumed. In reality the nature of the material is such that once deflections on the order of one third of the plate thickness are achieved the panel develops considerable resistance to deflection from the increasingly developing in-plane tension. Once the loading was applied by increments with a continual update on the deformed geometry, the computations gave results that were apparently in good agreement with the experimentally measured values. Thus the above material characterization seemed to be appropriate.

4. BENDING CHARACTERISTICS

Because the SDRWs deflect normal to their midplane in bending deformations it is important to be able to incorporate this behavior into a finite element analysis. Nothwithstanding the successful comparison beween computed and experimentally determined panel deflections mentioned above, it seemed initially somewhat opportunistic to assume that this behavior could be calculated accurately from the above data. But accuracy is important, because, most likely, the damage sustained by SDRWs is closely coupled to the shell oscillations in high sea states, which oscillations are in the form of out-of-mid-plane displacements.

Thus it was decided early on that bending stiffnesses should be determined: If the lamina properties should turn out to be too inaccurate to allow computation of the bending stiffnesses, then the direct measurements would provide the required information. If the comparison between lamina properties and measured compound properties of laminates were to be "reasonable", then these measurements would provide an additional check on our ability to provide a good characterization of the SDRW material for design purposes.

Three bending characteristics need to be investigated. The first is the twist behavior of a 3x2 ply wire composite. Figure 1 shows the mode of deformation intended. What is of interest here is the proportionality constant between the Gaussian curvature and the twisting moment effectively applied to the edges of the panel. We have experimented much with obtaining this relation, but have not succeeded in determining a twist stiffness. The reason is that the forces required to generate twist are so small compared to the weight of the panel, that repeat measurements would

result in wide data scatter. Yet it was very obvious that the forces required to generate panel twist were very small compared to any forces required to cause in-plane or out-of-plane bending deformations. We believe it, therefore, safe to assume that the twist stiffness of these panels can be set equal to zero for analysis purposes relative to the bending stiffnesses in the 3-wire and the 2-wires directions.

To determine the latter two stiffnesses it is important to recognize that simply subjecting panels of this type to lateral forces for moment production will generate deformations characteristic of "shear-beam" deformations rather than bending (see Figure 2). In use the SDRWs flex in such a manner that bending deformations result: It is necessary therefore in experiments geared to determine bending response to restrain the ends of the wires to move such that "plane sections remain plane".

For this reason the panels were designed such that the wire ends near the edge of the panel could not slide relative to each other. With that constraint the panel could be subjected to four-line bending as shown in Figure 3. This was accomplished by welding each successive longitudinal layer to steel plates at each end of the specimen. The deflections under this type of load were measured and a least squares fit was used to determine the curvature of cylindrical bending. The specimen geometry and the dimensions of the experimental apparatus is given in Figure 4. A photograph of this apparatus is given in Figure 5.

Figure 6 shows the relation between moment and curvature for the sample having three or two layers of wires run in the plane of curvature, i.e along the "length of the plate". Accordingly the relation between moment and

curvature for this case is (M=moment, R=radius of curvature, D=bending rigidity of the plate) for the three longitudinal wire specimens

$$M_3 = D/R = 1.39 \times 10^4/R \text{ in}^2 \text{ lbs.}$$

The subscript "3" indicates that three wires run the length of the specimen.

The counterpart for which the 2-wire layers run the length of the panel exhibits a moment-curvature relation as shown also as in Figure 6 so that for this case we have

$$M_2 = D/R = 4.19 \times 10^3/R \text{ in}^2 \text{ lbs.}$$

The subscript "2" indicates that two layers of wires run the length of the specimen.

With regard to the plate thickness we note that the outer thin layer of rubber adds virtually nothing to the plate bending stiffness. We have therefore used the distance between outer surfaces of the steel wires as the plate thickness, which is equal to 0.451 inches should that be an important parameter for comparative calculations.

5. COMPOSITE IN-PLANE SHEAR

In addition to the lamina properties it was also decided early on that in-plane shear performance of the 3x2 laminate should be determined in torsion tests on cylindrical specimens. As for the bending tests discussed above, it was intended to use this test method to either supplement the lamina data, or to provide a check on our ability to

compute composite properties from lamina information.

To date only one of the two torsion specimens has been recieved. This cylinder is a 3x2 ply wire composite with the 3 layers of wires parallel to the cylinder axis. The specimen is 24" long with a 6" inside diameter and has a wall thickness of 0.5" giving an outside diameter of 7".

The specimen was tested by clamping each end to its own aluminum cylinder with two 1/2" wide hose clamps. The aluminum cylinders were connected using a ball bearing; allowing them to rotate with respect to each other. One aluminum end cylinder was then rotated while the other was held fixed. The required torque and the resulting displacement were then measured. Since each end of the specimen was clamped with two hose clamps the length of the cylinder that was free and unencumbered was 21.5". This quantity was used in the subsequent data.

Figure 7 shows the relation between the twisting moment or torque and the angle of twist per unit length. For this case linear elasticity theory gives

$$M_3 = GJ\theta = 3.82\text{x}10^4\ \theta \quad \text{in}^2\ \text{lbs}$$

where

M = twist moment or torque

G = shear modulus

J = torsion constant of the cylinder

θ = angle of twist per unit length.

Alternatively, the product GJ is the torsional stiffness of the cylinder and is given as the slope in Figure 7. Once agin

the subscript "3" denotes three layers of wires along the length of the specimen.

Here since the cross-section is circular J reduces to the polar moment of inertia of the cross-section. Thus for this cylinder $J = 108.5\ in^4$. Consequently, the shear modulus is

$$G = 352 \text{ psi}.$$

What remains to be done is the test on the last torsion specimen. This test can be preformed promptly upon delivery of the specimen.

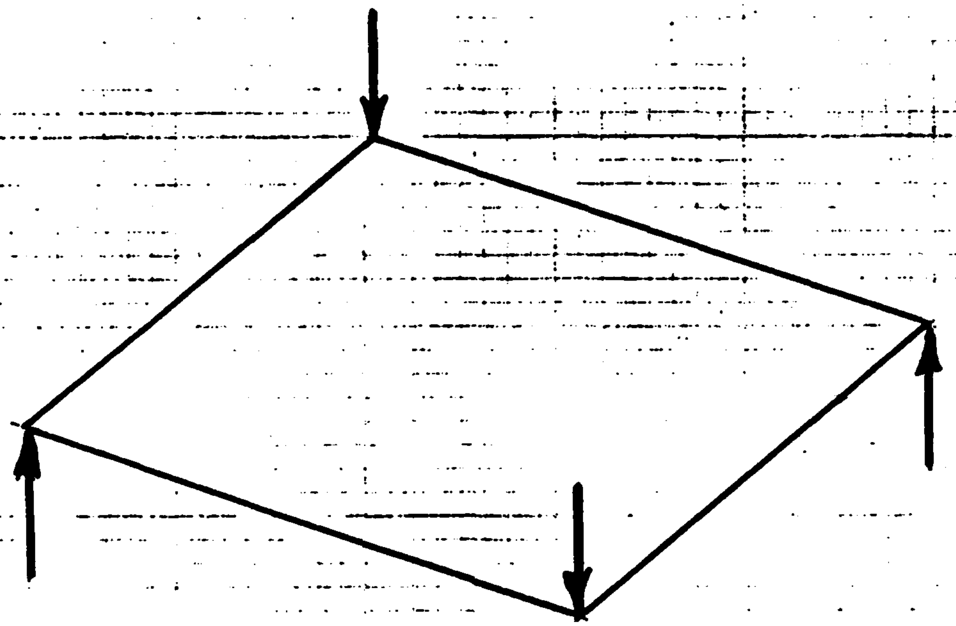

Figure 1. Twist test of 26.1" square x 0.56" thick panel.

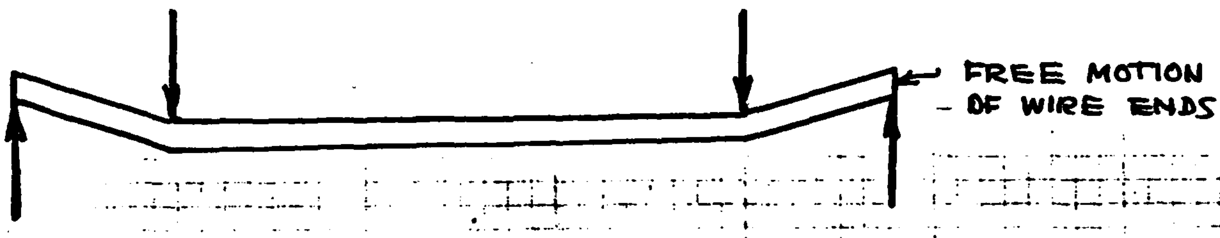

Figure 2. Shear-deformed beam or plate.

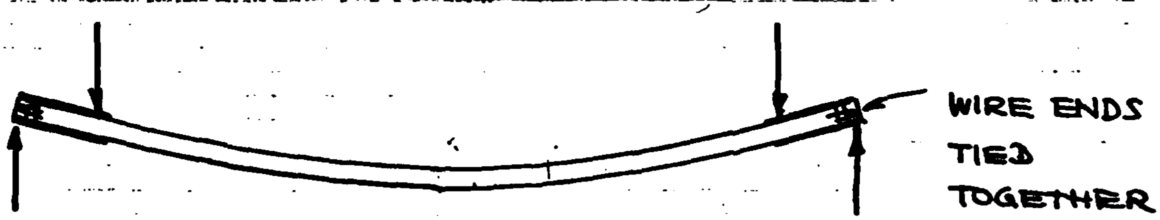

Figure 3. Bending of 3x2 and 2x3 plates.

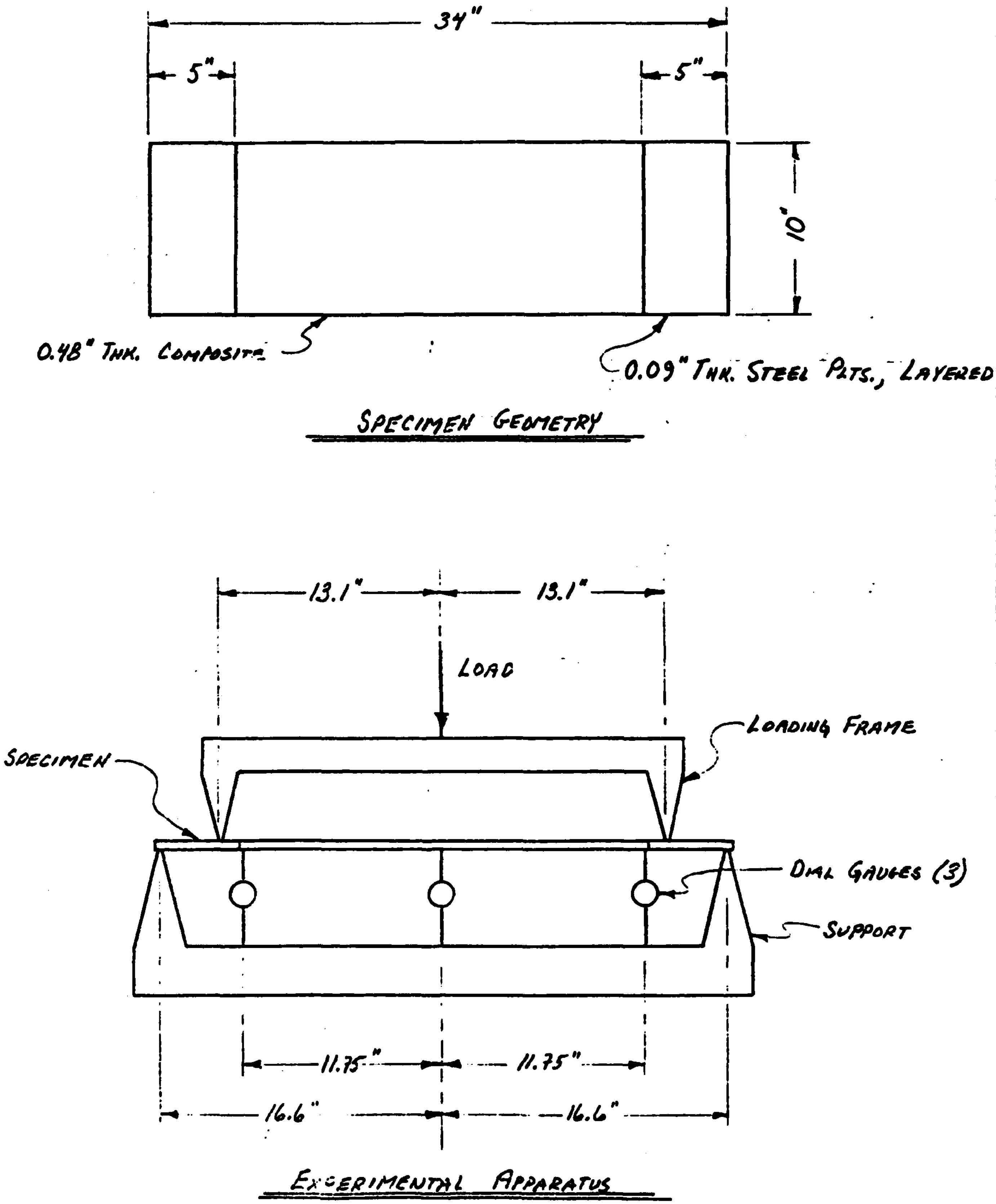

Figure 4. Specimen geometry and experimental configuration for the bending tests.

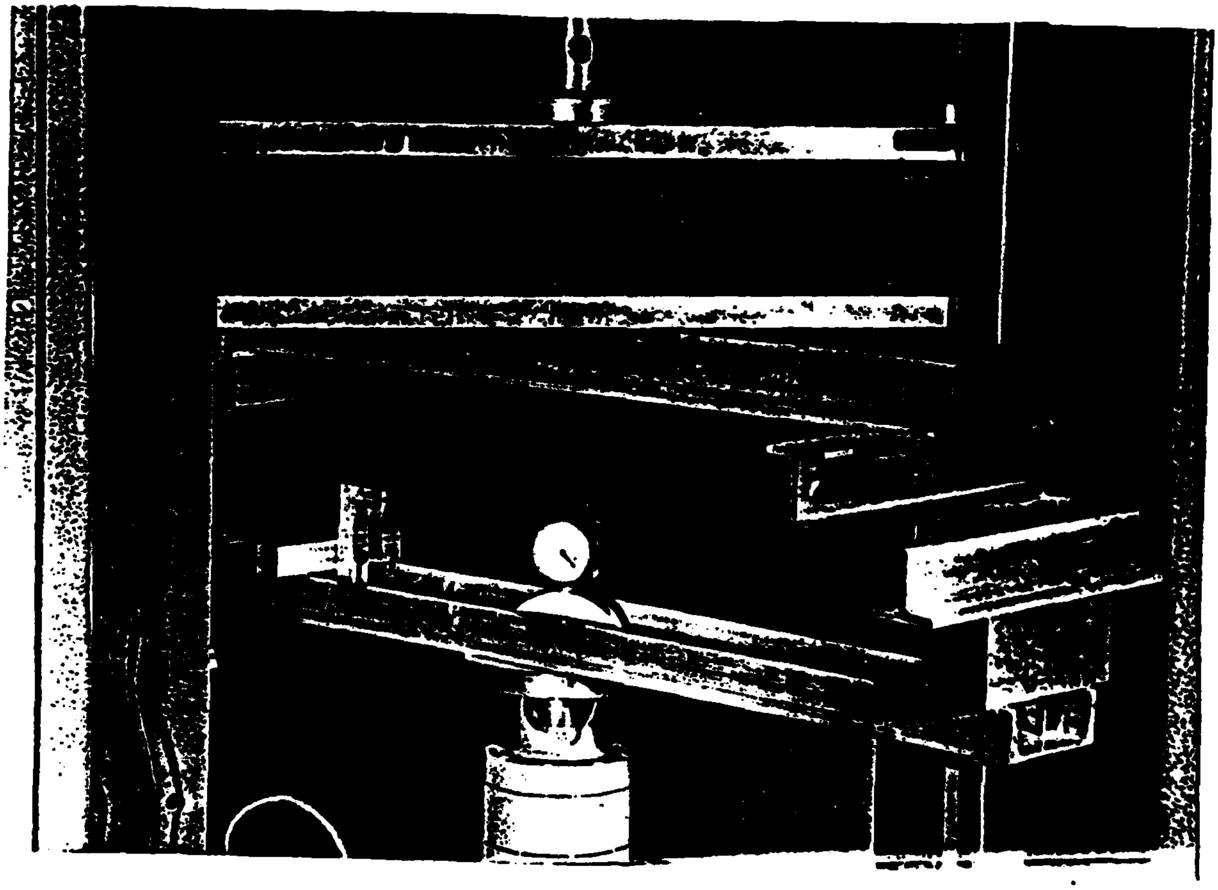

Figure 5. Experimental apparatus for the bending tests.

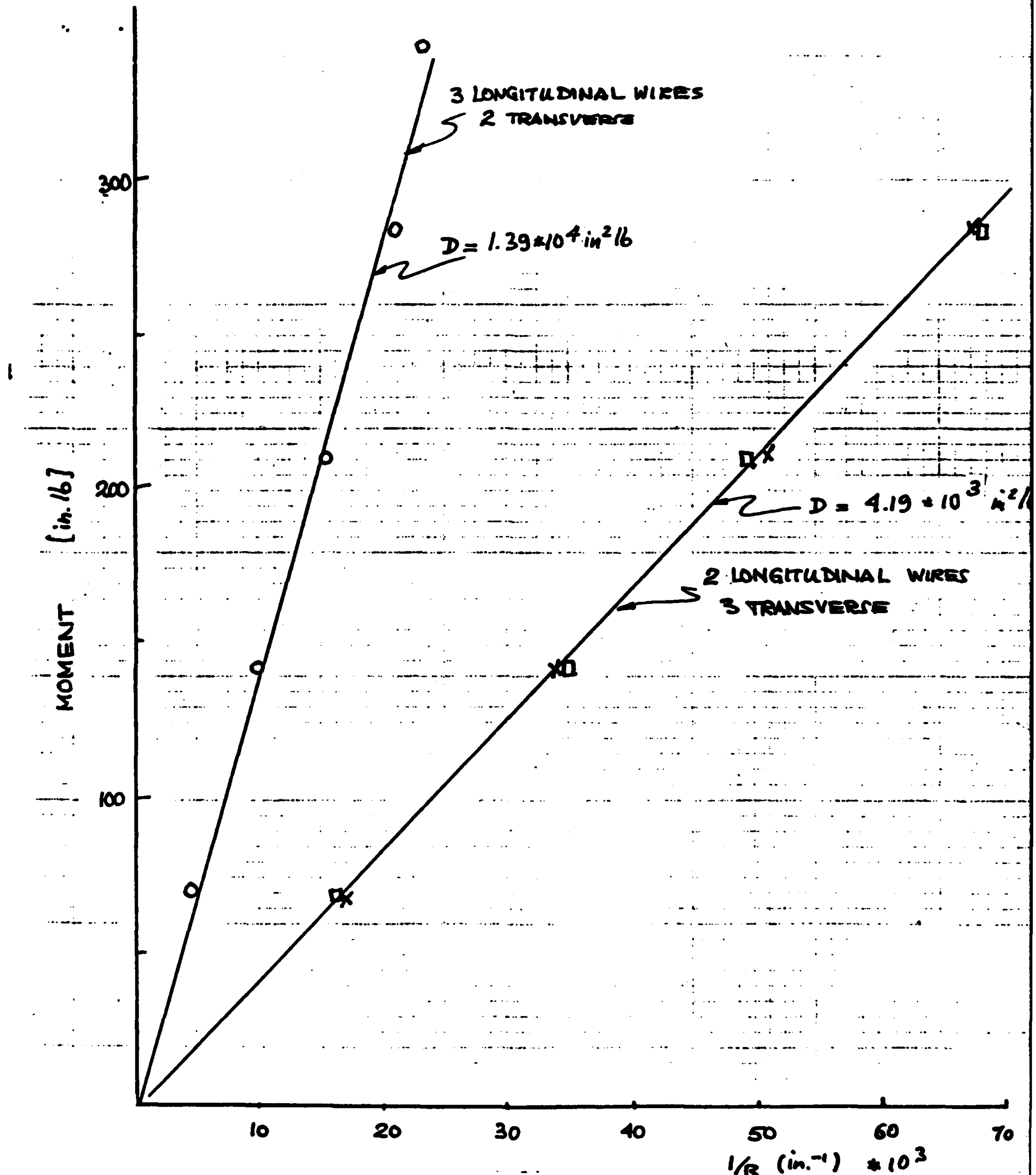

Figure 6. Relation between bending moment (M) and curvature (1/R).

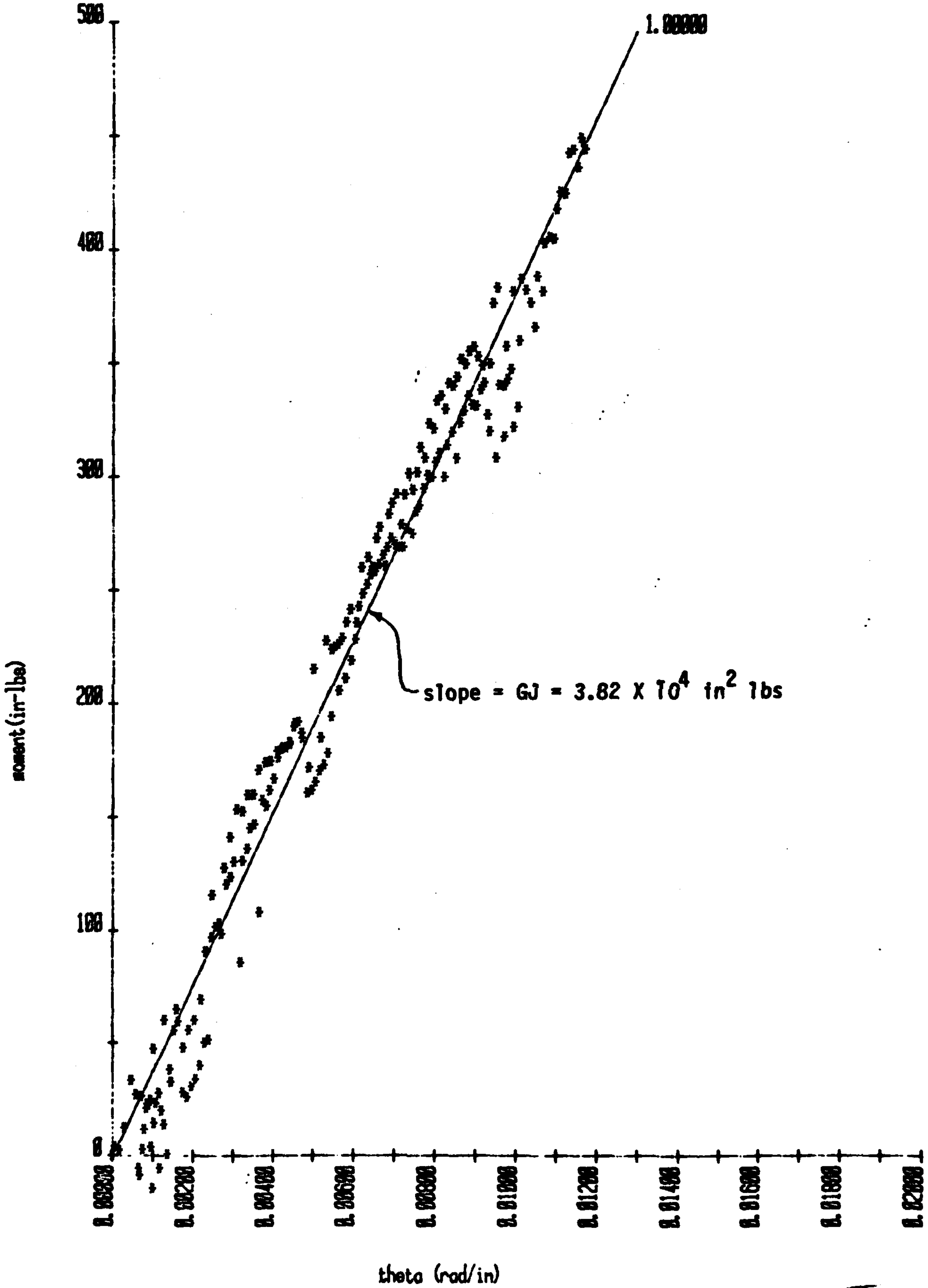

Figure 7. Relation between twisting moment (M) and angle of twist per unit length (θ).

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